compared with the ascertained direction of the earth-waves, confirm or upset my general supposition. But, if this were found to be correct, such observations would furthermore constitute, even in the absence of special seismic instruments, a certain amount of evidence as to the actual direction of the earth-waves on any particular occasion.

Similarly, a record of the exact direction of recumbent observers in regard to the points of the compass, might, when compared with their respective descriptions of the movements of objects about them, serve a similar purpose.

Man himself would thus to a certain extent—that is, as regards the local direction of the earth-waves—be his own seismometer. Possibly, some evidence on this subject might even now be obtained by comparing the descriptions of the appearances with the ascertained directions of the outlook of different observers. JOHN MARSHALL.

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On a Problem in Practical Geometry.

IN treatises on practical geometry rules are given by which an arc and its chord or an arc and its tangent may be divided proportionally, but they leave an error which is often too great.

By the following method the points of division move step by step towards their required positions until errors are of less than any assigned amount.

Let GMH be the chord (Fig. 1), M its middle point, AOB the perpendicular diameter. In AOB produced take a series of points B′B″B‴..., determined thus: BB′ = BG, B′B″ = B′G... Then evidently circles with centres at BB′B″..., passing through G, form a series of which each has on its circumference the centre of the succeeding one. These circles cut the line AM in a series of points A′A″..., and the arcs GAH, GA′H, GA″H... get rapidly nearer the straight line GH. Any point C on the given arc GAH may now move to its destination γ on the line GH by stepping up to each circle in the direction of its centre; along a path CC′C″..., made up of CC′ tending to B, C′C″ tending to B′, and so on.

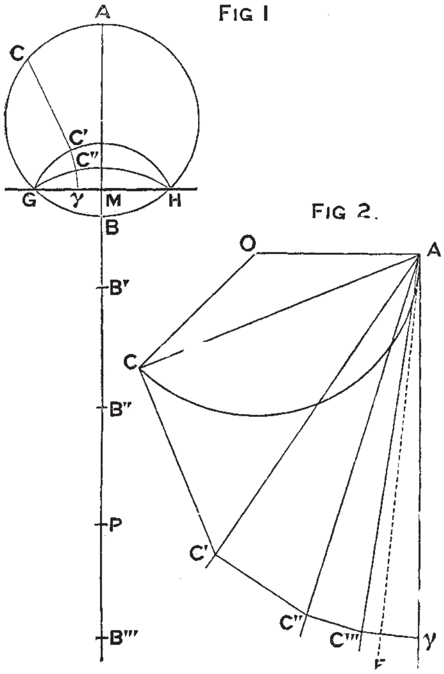

FIG I

FIG 2.

That all the arcs which this path crosses and the chord to which it tends are divided proportionally at the points CC′C″... γ follows from the almost obvious theorem that if the centre of one circle is on the circumference of another, lines drawn from that centre intercept arcs of the circles having a constant ratio.

If the circles become inconveniently large before the required approximation is reached, we may use the following: C′C″... are the centres of the circles inscribed in GCH, GC′H..., which are easy to construct. Also it may be noticed that the angle made with AO by each of the parts of CC′C″... is half that made by the preceding part, and the process may be brought to an end at any stage with progressive accuracy by making the last angle one-third instead of half of the preceding one.

In Fig. 1 the process is closed after the second stage by drawing the last line (C″γ) not towards B″, but towards the middle point P of B″B‴. This may be done as soon as the last arc GC″H comes to be less than a quadrant.

When the chord becomes the tangent AT at A, the points AA′A″... coincide, all the circles have AT touching them at A, the radius of each is half that of the succeeding one, the arcs intercepted AC, AC′, AC″... are equal, and so we get in the limit Aγ, the length of the arc AC laid out on the tangent.

But in Fig. 2 an alternative construction is shown. Bisect TAC by AC′, TAC′ by AC″, and so on. Draw CC′, C′C″... at right angles to AC, AC′... The process is shown closed after the third stage by drawing C‴γ at right angles, not to AC‴, but to a line AF such that C‴AF is one-third of C‴AT. In the result Aγ is equal to arc AC.

JOHN BRIDGE.

Caught by a Cockle.

I HAVE often intended writing to you describing a curious occurrence which I witnessed on the coast of Queensland in September 1889, but I have as often forgotten to do so when the opportunity came. While out shooting, along a sandy beach, I noticed a small muddy patch just covered by the rising tide. In this I observed a bird, a sand-piper, which seemed to be striving in vain to rise. I could not think how the bird had become caught, but on coming up to it I found that one claw of one foot was firmly held by a large cockle (about 1½ in. by 2 in.). Of course the bird would have been drowned eventually (though the benefit to be derived by the cockle seems rather problematical); and though it seemed to be aware of its danger, yet it had made no attempt to free itself by trying to bite through the claw, as one sometimes reads of animals doing when caught in traps. As I believe this is rather an uncommon incident, I must make that my excuse for troubling you. D. McNABB.

H.M.S. *Dart*, New Hebrides, July 3.

ON STELLAR VARIABILITY.

ON the hypothesis of the meteoritic origin of the various orders of cosmical bodies there is a grand and orderly variation, both in light and colour, in the case of every undisturbed swarm during its condensation from its most nebulous condition to that of a cool dark globe.

As by virtue of the ordinary evolutionary process an *undisturbed* swarm successively passes through the changes the results of which define the various groups, the light will wax through Groups I. to IV., and then wane till it is finally extinguished; at the same time the colour sequences will be successively passed through. But with such a variability as this, compared with the period of which our *annus magnus* is but a point of time, we have now nothing to do. We have to deal really with *disturbed* swarms or with double or multiple swarms through their various stages of condensation.

Let us take the purely disturbed swarms first. Imagine a nebula, sparse, and therefore so dim as hardly to be visible at all. Then, further, imagine the appulse of another, or the approach of a meteoritic stream. We shall have the condition which must bring about increased luminosity; the outburst may be short or sudden; the greater luminosity may last a short or a long time; the dying down of the light may be fast or slow. In that we shall have the possibilities of new and dying stars.

If the spectrum of the light produced by this clashing be observed, we may not have precisely the same phenomenon as that observed in the various groups defining the result of the orderly condensation of a single swarm, for the simple reason that we shall have two swarms or bodies to deal with. Even if the very highest temperature is reached, we shall not have *exactly* the same spectrum as that presented by Group IV.

The most stupendous case illustrating the above remarks is to be found in the Pleiades, the true structure of which has been revealed to us by Mr. Roberts. The principal stars are not really stars at all; they are simply *loci* of intercrossings of meteoritic streams, the velocities of which have been sufficiently great to give us, as the result of collisions, a temperature approaching that of α Lyræ, so far as we can judge by the spectrum; but that the α Lyræ conditions are not present is evidenced by the fact that in Pleione the broad dark hydrogen lines have a bright thin line running down their centres, indicating that we have intensely-heated hydrogen outside that which is absorbing.

So long as these meteoritic streams are interpenetrating and disturbing each other, so long the Pleiades will shine; but their light may soon cease if the disturbance comes to an end, for we are not dealing with masses of vapour like α Lyræ. Indeed, one of them seems to have already become invisible. Of the seven daughters of Atlas, one has disappeared. The "septem radiantia sidera" are seven no longer. The seventh had vanished before the time of Aratus.

> "The Pleiades; small the region
> They fill, and pale the light they dart.
> Seven journeyers men call them
> Though only six are visible to ken.
> No star, I wis, has vanished from Heaven's floor
> Within mortal tradition, and idly is that number
> Fabled. Natheless seven the names they bear:
> Alcyone, Merope, Celæno, Electra,
> Sterope, Taygete, and stately Maia."[1]

At the beginning of the action to which I have ascribed the present light of the Pleiades, we should have the appearance of a "new star," and the greater the light produced and the more sudden the outburst the more certainly would the appearance of a new star be chronicled. Many such stars have burst forth, and the phenomena recorded have been entirely in harmony with the explanation afforded by the hypothesis; but, as the discussion of these phenomena is not yet complete, I shall not in the present article touch further upon them; but I may point out that, before the existence of "variable stars" was recognized, as it is now, the increase in magnitude of a variable at maximum, rendering visible to the naked eye what was before invisible, was attributed to the creation of a new star. Hence it is that the first work done on the periodicity of variable stars grew out of observations of so-called Novæ.

Leaving on one side, then, any question of Novæ, we will inquire into the growth of our knowlege of stars the light of which is known to wax and wane with more or less regularity, and see to what causes this variability has been ascribed. We have to consider those shorter periods of light-variation, well within human ken, light-changes which, instead of taking millions and perhaps billions of years, are undergone in a few days, or weeks, or months. Such changes have been abundantly chronicled from the earliest times and acknowledged to be among the most mysterious phenomena presented to us in the skies.

In this historical survey we must first consider the case of Mira or ο Ceti. It is now nearly three centuries ago since Fabricius noticed this star (August 1596), thinking it to be a *nova*, and watched its disappearance in the following October.[2]

Not only Fabricius but Kepler looked upon Mira Ceti as a new star similar to those of 1572 and 1604. Indeed, it was regarded as such until 1638, when some observations by Phocylides Holwarda brought out for the first time the fact that the changes in magnitude repeated themselves. The work done by this astronomer is quoted by Hevelius.

Holwarda first observed the star in December 1638, when it was brighter than a third magnitude; he watched it decrease to the fourth, and disappear during the summer of 1639. On December of the same year he again observed it. There is no doubt, indeed, that Holwarda was the first to demonstrate by these observations that the light of stars is liable to periodic changes in intensity.

Fullenius, a teacher of mathematics at Franecker, was the next to observe Mira. He noted that the star was visible on September 23, 1641, and the same date in the following year. In August 1644, however, no trace of it could be made out.

Junquis, a professor at Hamburg, recorded that Mira was of the third magnitude on February 18, 1647, and was invisible from July 1648 to November of the same year.

It was Hevelius, however, who made the first detailed investigation into the variations of the light of this star. Beginning in January 1648 he assiduously watched the changes in magnitude until March 1662, and placed the question of variability beyond the possibility of a doubt.

During the fifteen years of observation Hevelius saw the star go through its changes in magnitude many times, and noted that it was always invisible for several months in the year. He did not, however, determine the period, although it will be seen that the following observations would have been sufficient for him to have deduced an approximate value:—

Sept. 10, 1660—"Instar stellæ 4 magn. fere."
Aug. 20, 1661—"Vix quartæ magnitudinis extitit."
Interval, 344 days.
Sept. 20, 1660—"Æqualis illi in ore Ceti."
Aug. 29, 1661—"Æqualis illi in ore Ceti."
Interval, 353 days.

The determination of the period of Mira Ceti was deduced by Bouillaud in 1667 from all the observations which had been made from its discovery in 1638 to 1660. This discussion occurs in a rare book having the title "Ismaelis Bullialdi ad Astronomos monita duo: Primum de Stella Nova, quæ in Collo Ceti ante annos aliquot visa est. Alterum, de nebulosa in Andromedæ cinguli parte Borea, ante biennium iterum orta."

A review of the book appeared in the first volume of the Philosophical Transactions (p. 381), from which the following account of Bouillaud's conclusions have been taken:—". . . That one *period* from the *greatest phase* to the next consists of 333 days; but that the interval of time betwixt the times of its beginning to appear equal to stars of the *sixth magnitude*, and of its ending to do so consists of about 120 days; and that its *greatest appearance* lasts about fifteen days: all which yet he would have understood with some latitude.

"This done, he proceeds to the investigation of the causes of the vicissitudes in the emersion and disappearance of this star, and having determined that the apparent increase and decrement of every lucid body proceeds *either* from its changed distance from the eye of the observer, *or* from its various site and position in respect of him, whereby the angle of vision is changed, or from the increase or diminution of the bulk of the lucid body itself; and having also demonstrated it impossible that this star should move in a *circle* or in an *ellipsis*, and proved it improbable that it should move in a *strait line*, he concludes that there can be no other genuine, or at least no other more probable cause of the emersion and occultation than this: That the bigger part of that round body is obscure and inconspicuous to us, and its lesser part lucid, the whole body turning about its own center and one axe, whereby for one determinate space of time it exhibits its lucid part to the Earth,[1] for another, subducts it, it not being likely that fires should be kindled in the body of that star, and that the matter thereof should at certain times take fire and shine, at other times be extinguist upon the consumption of that matter. . . ."

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[1] Poste's translation, p. 13.

[2] Kepler, "De Stella," chap. xii. p. 112.

[1] Here we have the germ of Sir Wm. Herschel's reference to the action of varying amounts of spotted surface; Maupertius' idea of rotatory disks; and Prof. Pickering's suggestion of axes of different lengths.

This, so far as I know, is the first proposed explanation of stellar variability on record.

The next star in which variability of light was observed was χ Cygni. Kirch's observations made in 1686 and subsequent years were communicated to the Royal Society. He observed the star with the aid of an eight-foot tube in August 1687. It became visible to the naked eye in October, increased in brightness and reached a maximum in November, and finally disappeared. This observer also found that the star had always the same brightness at a maximum, and in assigning it a period of 404½ days, he noted that this duration was irregular.

These observations bring us to the time of Newton, who at once saw that the cause of true Novæ must be distinct from that producing variability pure and simple. He ascribed the sudden appearance of new stars as possibly due to the appulse of comets :—

"Sic etiam stellæ fixæ, paulatim expirant in lucem et vapores, cometis in ipsas incidentibus refici possunt, et *novo alimento accensæ pro stellis novis haberi.* Hujus generis sunt stellæ fixæ, quæ subito apparent, et sub initio quam maxime splendent, et subinde paulatim evanescunt. Talis fuit stella in cathedra Cassiopeiæ quam Cornelius Gemma octavo Novembris 1572 lustrando illam cœli partem nocte serena minime vidit ; at nocte proxima (Novem. 9) vidit fixis omnibus splendidiorem, et luce sua vix cedentem Veneri. Hanc Tycho Brahæus vidit undecimo ejusdem mensis ubi maxime splenduit ; et ex eo tempore paulatim decrescentem et spatio mensium sexdecim evanescentem observavit."[1]

But with regard to the ordinary variables, he accepts Bouillaud's suggestion, and adds another :—

"Sed fixæ, quæ per vices apparent et evanescunt, quæque paulatim crescunt, et luce sua fixas tertiæ magnitudinis vix unquam superant, videntur esse generis alterius, et revolvendo partem lucidam et partem obscuram per vices ostendere. Vapores autem, qui ex sole et stellis fixis et caudis cometarum oriuntur, incidere possunt per gravitatem suam in atmosphæras planetarum et ibi condensari et converti in aquam et spiritus humidos, et subinde per lentum calorem in sales et sulphura et tincturas et limum et lutum et argillam et arenam et lapides et coralla et substantias alias terrestres paulatim migrare."

Both Montanari in 1669 and Maraldi in 1692 observed that the magnitude of β Persei or Algol was variable.

The information they gave with respect to changes of the star from the second to the fourth magnitude, though important, was not very definite, and it was left to Goodricke, an English astronomer, to discover, in 1782, the periodicity of these variations and to conclude :—(1) "That the star changes from about the second to the fourth magnitude in nearly three hours and a half and then back to the second magnitude again in the same time. (2) That this variation occurs about every two days and twenty-one hours."[2] Flamsteed observed the star in 1696, and found it to be of the third magnitude, and Goodricke, by comparing it with one of his own, deduced the more accurate value of 2 days, 20 hours, 48 minutes, 56 seconds. At the end of the observations Goodricke added the note: —"I should imagine that the cause of this variation could hardly be accounted for otherwise than either by the interposition of a large body revolving round Algol, or some kind of motion of its own whereby part of its body covered with spots or such-like matter is periodically turned towards the earth."

Another variable observed by Goodricke was β Lyræ. His first observations brought him to the conclusion that the star had a periodical variation of nearly six days and nine hours, but a further investigation showed that the true period was twelve days nineteen hours, there being two maxima and minima. At one minimum the magnitude of the star is between four and five, at the other between three and four.

Zöllner, in a relatively recent discussion advances very little beyond the views advocated by Newton. In considering the main causes of variability, he lays the greatest stress upon an advanced stage of cooling, and the consequent formation of scoriæ which float about on the molten mass. Those formed at the poles are driven towards the equator by the centrifugal inertia, and by the increasing rapidity of rotation they are compelled to deviate from their course. These facts, and the meeting which takes place between the molten matter, flowing in an opposite direction, influence the form and position of the cold non-luminous matter, and hence vary the rotational effects, and therefore the luminous or non-luminous appearance of the body to distant observers. This general theory, however, does not exclude other causes, such as, for instance, the sudden illumination of a star by the heat produced by collision of two dark bodies, variability produced by the revolution of a dark body, or by the passage of the light through nebulous light-absorbing masses.

Among modern inquirers Prof. Pickering has been more original in his suggestions. He has shown that the light-curves of some stars may be explained by supposing them to have axes of different lengths, with dark portions at the ends, symmetrically situated as regards the longer axis.

In the following discussion of the cause of variability suggested by the meteoritic hypothesis, I shall divide variability into regular and irregular, defining regularity by constantly recurring maxima and minima on the light-curves.

THE CAUSES OF VARIABILITY SUGGESTED BY THE METEORITIC HYPOTHESIS.

Regular Variability.—All regular variability in the light of cosmical bodies is caused by the revolution of one swarm or body round another (or their common centre of gravity).

In the case of the revolution of one swarm round another an elliptic orbit is assumed, and the light *at maximum* is produced by collisions among the meteorites at periastron.

In the case of the revolution of a swarm round a condensed body, the light *at maximum* is produced by the tidal action set up in the secondary swarm.

In the case of one condensed body revolving round another, the light *at minimum* is caused by an eclipse of one body by the other. This can only happen when the plane of revolution of the secondary body passes very nearly through the earth.

Irregular Variability.—All irregular variability in the light of cosmical bodies is caused (*a*) by the revolution of more than one swarm or body round another (or their common centre of gravity) ; or (*b*) by the interpenetration of meteoritic sheets or streams.

In the case of the revolution of more than one swarm round another in elliptic orbits, the irregular maxima are caused by differences of period and periastric conditions

So far as I know, the only previous explanation of variability on such a basis as the one above stated, which assigns the revolution of one mass round another as a cause of variability, is the one we owe to Newton, who suggested that such stellar variability as we are now considering was due to conflagrations brought about at the maximum by the appulse of comets ; and no doubt his idea would have been more thoroughly considered than it has been hitherto, if for a moment the true nature of the special class of bodies we are now dealing with had been *en évidence.* We know that some of them at their minimum put on a special appearance of their own in that haziness to which I have before referred as having been observed by Mr. Hind. My researches show that they are all nebulæ in a further stage of condensation, and such a disturbance as the one I have suggested would be certain to be competent to increase the luminous radiations of such a congeries to the extent indicated.

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[1] "Principia," p. 525 (Glasgow, 1871).

[2] "Phil. Trans., 1783, p. 474.

Some writers have objected to Newton's hypothesis on the ground that such a conflagration as he pictured could not occur periodically; but this objection I imagine chiefly depended upon the idea that the conflagration brought about by one impact of this kind would be quite sufficient to destroy one or both bodies, and thus put an end to any possibilities of rhythmically recurrent action. It was understood that the body conflagrated was solid like our earth. However valid this objeetion might be as urged against Newton's view, it cannot apply to mine, because in such a swarm as I have suggested, an increase of light to the extent required might easily be produced by the incandescence of a few hundred tons of meteorites.

I have already referred to the fact that the initial species of the stars we are now considering have spectra almost cometary, and this leads us naturally to the view that we may have among them in some cases swarms with double nuclei—incipient double stars, a smaller swarm revolving round the larger condensation, or rather both round their common centre of gravity. In such a condition of things as this, it is obvious that, as before stated, in the swarms having a mean condensation this action is the more likely to take place, for the reason that at first the meteorites are too sparse for many collisions to occur, and that, finally, the outliers of the major swarm are drawn within the orbit of the smaller one, so that it passes clear. The tables, which shall be given hereafter, show that this view is entirely consistent with the facts observed, for the greater number of instances of variability occur in the case of those stars in which, on other grounds, mean spacing seems probable.

I propose here to consider the suggested cause of variability somewhat in detail. I will begin with Groups I. and II.

In these groups the variability is produced by the revolution of one or more smaller swarms round a central swarm, the maximum luminosity occurring at periastron, when the revolving swarms are most involved in the central one.

According to the theory, the normal condition is that which exists at minimum, and in this respect it resembles that suggested by Newton—namely, that the increase of luminosity at maximum was caused by the appulse of comets. All other theories take the maximum as the normal condition, and the minimum as a reduction of the light by some cause—large proportion of spotted surface, or what not.

Anything which in the normal minimum condition of light-equilibrium will increase the amount of incandescent gas and vapour in the interspaces will bring about the appearance of the hydrogen lines and carbon flutings as bright ones. The thing above all things most capable of doing this in a most transcendental fashion is the invasion of one part of the swarm by another one moving with a high velocity. This is exactly what I postulate. The wonderful thing under these circumstances then would be that bright hydrogen and carbon should *not* become more luminous, not only in bright-line stars, but in those the spectrum of which consists of mixed flutings, bright carbon representing the radiation.

We may consider three cases of revolution. Taking that first in order which will give us the greatest light range, we find that this obviously will occur in those systems in which the orbits are most elliptic and the periastric distances least.

On the other hand, a mean ellipticity will give us a mean range.

In these two cases, to account for the greatest difference in luminosity at periastron passage, we have supposed the minor swarm to be only involved in the larger one during a part of its revolution, but we can easily conceive a condition of things in which the orbit is so nearly circular that it is almost entirely involved in a larger swarm. Under these conditions, collisions would occur in every part of the orbit, and they would only be more numerous at periastron in the more condensed central part of the swarm, and it is to this that I ascribe the origin of the phenomena in those objects—a small number—in which the variation of light is very far below the normal range, one or two magnitudes instead of six or seven.

Now it is at once obvious that we should get more variability in these early groups than in any of the more condensed ones, for the reason that in the latter we require the conditions either that the plane of revolution should pass through the earth, or that the light of the central star shall be relatively dim.

This point is best studied in relation to Group II.

The total number of stars included in Argelander's Catalogue, which deals generally with stars down to the ninth magnitude, but in which, however, are many stars between the ninth and tenth, is 324,118. The most complete catalogue of variables (without distinction) that we have has been compiled by Mr. Gore, and published in the Proceedings of the Royal Irish Academy (Series II., vol. iv., No. 2, July 1884, pp. 150–163). I find 191 known variables are given; of these 111 are in the northern hemisphere and 80 in the southern hemisphere.

In the catalogue of *suspected* variable stars given in No. 3 of the same volume (January 1885, pp. 271–310), I find 736 stars, of which 381 are in the northern and 355 in the southern hemisphere. Taking, then, those in the northern hemisphere, both known and suspected, we have the number 492. We have, then, as a rough estimate for the northern heavens one variable to 659 stars taken generally.

The number of objects of Group II. observed by Dunér, and recorded in his admirable memoir, is 297; of these 44 are variable. So that here we pass from 1 in 657 to 1 in 7. Of the great development of variability conditions in this group then there can be, therefore, no question.

Further, while by the hypothesis there is no limit to the increase of luminosity, the variability presented by these objects is remarkable for its great range. The light may be stated in most general terms to vary about six magnitudes—from the sixth to the twelfth. This, I think, is a fair average; sometimes a difference of eight magnitudes has been observed; the small number of cases with a smaller variation I shall refer to afterwards. A variation of six magnitudes means roughly that the variable at its maximum is somewhere about 250 times brighter than at its minimum; a variation of eight magnitudes means that it is 1600 times brighter at maximum than minimum.

These values alone would indicate a condition of things in which the minimum represents the constant condition, and the maximum, one imposed by some cause which produces an excess of light. These various conditions having been premised in considering these groups, I will first deal with the nebulæ.

That many of the nebulæ are variable is well known, though, so far as I am aware, there are no complete records of the spectroscopic result of the variability. But bearing in mind that in some of these bodies, such as the Dumb-bell Nebula, we have the olivine line almost by itself; and in others, which are usually brighter, we have the lines of hydrogen intensified, as in Orion; and in others, more condensed still, the flutings of carbon added, as in Andromeda; it does not seem unreasonable to suppose that any increase of temperature brought about by the increased number of collisions should increase the intensity of the lines of hydrogen or carbon in the spectrum of a nebula.

The observations already accumulated show conclusively that in the nebulæ—even those so far condensed as the one in Andromeda—the temperature is low; in other words, the meteorites are very far apart; regular variability, therefore, would for this reason be very difficult to detect. It is probable, therefore, that in all the cases previously recorded, we are not dealing with the results of rhythmic action, but the interpenetration of nebulous streams or sheets. When, however, we come to the stars—that is, the more condensed nebulæ—in Group I. and Group II., the temperature is higher, the condensation is greater, and the interaction of double or multiple nebulæ can be more easily traced. This fundamental difference of structure between these bodies and stars like the sun should be revealed in the phenomena of variability; that is to say, the variability of the uncondensed swarms should be different in *kind* as well as in degree from that observed in bodies like the sun or α Lyræ, taken as representing highly condensed types.

Since the stars with bright lines, as I have shown, belong to the former group, and since, therefore, they are very akin to nebulæ, we might, reasoning by analogy, suppose that any marked variability in their case also would be accompanied by the coming out of the bright hydrogen lines. This is really exactly what happens both in β Lyræ and in γ Cassiopeiæ. In β Lyræ the appearance of the lines of hydrogen has a period of between six and seven days, and in γ Cassiopeiæ they appear from time to time, although the period has not yet been determined.

Another star of Group I., η Argûs, is also remarkable from the fact that its light varies in the same sort of way. This star is in the southern hemisphere, and during the last twenty or thirty years a considerable discussion has been going on among astronomers as to whether the surrounding nebula is or is not changing its position with regard to the star in question, which has a bright-line spectrum like β Lyræ, and a period not of thirteen days, but of seventy years. The light varies from the sixth to the first magnitude.

Leaving Group I. and coming to Group II., there is one star, Mira Ceti, whose variations in light-intensity may be taken as characteristic. The history of the discovery of this star's variabiltty has already been given. What happens to it in just a little less than a year is this. First, it is of the second magnitude, and then in about eighty days it descends to the tenth, and, so far as observations with ordinary instruments go, it is invisible. In about another hundred days it again becomes visible as a star of the tenth magnitude. It then increases its light to the second magnitude, and begins the story over again. But sometimes at the maximum its brilliancy is not quite constant. That is to say, sometimes it goes nearer the first magnitude than the second. What happens to the light of the star below the tenth magnitude it is not easy to say. What one knows is that to some telescopes it remains invisible for about 140 days or something like that, and then it begins its cycle over again.

I owe to the kindness of Mr. Knott the opportunity of studying several light-curves of "stars" of this group, and they seem to entirely justify the explanation which I have put forward. It is necessary, however, that the curves should be somewhat carefully considered, because in some cases the period of the minimum is extremely small, as if the secondary body scarcely left the atmosphere of the primary one but was always at work. But when we come to examine the shape of the curves more carefully, what we find is that the rise to maximum is extremely rapid: in the case of U Geminorum, for instance, there is a rise of five magnitudes in a day and a half; whereas the fall to minimum is relatively slow. The possible explanation of this is that the rise of the curve gives us the first sudden luminosity due to the collisions of the swarms, while the descent indicates to us the gradual toning down of the disturbance. If it be considered fair to make the descending curve from the maximum exactly symmetrical with the ascending one on the assumption that the immediate effect produced is absolutely instantaneous, then we find in all cases that I have so far studied that the star would continue for a considerable time at its minimum.

Broadly speaking, then, we may say that the variables in this group are *close doubles;* the invisibility of the companion being due to its nearness to the primary or to its faintness.

We now pass from Groups I. and II. to III., IV., and V. These contain the hottest, and therefore brightest bodies in the heavens. They are, moreover, more condensed than those we have considered. On this ground, their normal light cannot be *increased* to any very great extent by any constantly recurring action, but it may be *reduced* by eclipses caused by the revolution of still further condensed secondary swarms. The nearer the primary, and therefore the smaller the period of the secondary body, the more likely is the eclipse to occur regularly. There are several Group IV. stars of this class, notably Algol, to the first observations of which we have already referred.

This body, which is always visible in our latitudes, well illustrates this class of variable. If we take the beginning of a cycle, it is a star of the second magnitude; suddenly in three hours it goes down to the fourth, and then it comes up in another three hours to the second, and goes on again for very nearly three days; and then it goes down again, comes up again, and goes on again for another three days, and so on.

There is another star very like this—a star which is in 81° N. declination, No. 25 in Argelander's Catalogue. The difference between Algol and this is that the rise and fall are a little more rapid. Its light is feeble for about the same time as the other one, but at the bottom the curve is flat, by which I mean that, instead of going suddenly down and coming suddenly up again, it stops at its least luminosity for some little time.

Prof. Pickering[1] has demonstrated by photographs of the spectra of Algol that Goodricke's explanation of its periodical variability is correct, the companion having no light of its own. In the case of the star D. 81° N. 25 there must be luminosity from the star which eclipses the other. And a very beautiful justification of this view has recently been noted, because, although there is no change in the spectrum of Algol, there is a considerable change in the spectrum of the star, the bottom curve of which is flat, showing that probably the companion has an absorbing action of some kind on the light of the central star passing through it or its surroundings. The light practically changes very much as our sunlight would change if it had to pass through the atmosphere of another sun somewhat like itself coming between us.

In Group VI. we again have a new condition. In these stars the light is relatively faint, and the variation is doubtless due to swarms of meteorites moving round a dim or nearly dark body, the maximum occurring at periastron when the tidal action in the swarm is greatest; hence the addition of the light of what we with our solar conditions should term a large comet would make a great difference in the total radiation.

J. NORMAN LOCKYER.

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[1] Proc. Amer. Acad. Sci., vol. xvi. p. 17